

Confinement and energy balance in a rotating plasma

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Under laboratory conditions particle losses from a magnetized plasma to the walls of a surrounding vessel will produce a neutral particle flux which reenters the plasma region. Even at very high temperatures, where the plasma is almost fully ionized, this gives rise to interactions between charged and neutral particles which cannot always be neglected. The situation will be equivalent to that of a partially ionized gas where not only coulomb collisions between charged particles are operative but also collisions between charged and neutral particles leading, among other things, to ionization, charge exchange and elastic scattering. The latter processes also affect the "burnout" conditions of the plasma as well as the diffusion of charged particles into the loss cones of a mirror machine.

It has earlier been suggested to confine a plasma in the magnetic field of a current loop (Lehnert 1958; Colgate 1959), the heating of the plasma being provided, e.g., by a transverse electric field which sets the plasma into rotation around the axis of symmetry (Lehnert 1959). In a study of the motion of an individual particle has been shown that particles under certain conditions become trapped completely inside a "bag" of magnetic field lines which is "sealed" by the centrifugal force (Bonnevier and Lehnert 1959). In the case where the electric and magnetic fields are perpendicular all over the confinement region it can be shown that the angular velocity of rotation becomes constant along a field line. The situation resembles that of a planetary atmosphere, where the particles are trapped by a gravitation field, provided that their thermal velocity falls below the escape velocity. To determine the situation completely the relation between the centrifugal force and the thermal energy of the plasma has to be deduced from the energy balance.

For this purpose a macroscopic theory has to be established where conservation of mass, charge, momentum and energy is taken into account as well as interactions between all particles being involved. Such a theory can be established for a three-fluid model consisting of an ion and an electron gas moving in a neutral gas, the latter being essentially at rest. It is thereby found not to be necessary to derive the energy equation in terms of the joint action of electromagnetic and mechanical changes of state.

For an axially symmetric plasma the angular velocity is again found to be constant along a magnetic field line to a high degree of approximation. This is consistent with the conclusion earlier drawn by Ferraro (1937) about the isorotation of a magnetized star. Two special cases can be treated in detail, one with vanishing heat conductivity and one with infinite heat conductivity in the direction along the magnetic field lines. Due to the relatively high thermal conductivity

along the field in a high temperature plasma the latter case is more likely to occur. If charge exchange is neglected the density distribution then becomes

$$\rho/\rho_0 = \exp [-5 (r_0^2 - r^2)/2 r_1^2], \quad (1)$$

where ρ is the density at a point (r, φ, z) in a cylindrical coordinate system with z along the axis of symmetry and $z=0$ indicates the "equatorial" plane. Index $(_0)$ refers to the circle where the toroidal surface generated by the field line through (r, φ, z) intersects the equatorial plane and r_1 is the radius at which the same surface meets a bounding material wall. Eq. (1) can be shown to be analogous to the "barometer formula" where the gravitational field has been substituted by the centrifugal field. The result seems to be applicable up to a temperature of about 10^7 °K. Above this value the confinement is impaired by charge exchange collisions and elastic scattering of neutrals which enter the plasma region. The theory predicts that the energy loss by escaping particles should be several orders of magnitude less in the field of a current loop than in earlier described homopolar machines.

Even if particle losses are reduced to a minimum instabilities might increase the energy dissipation catastrophically and frustrate the attempts to obtain a high temperature. It should only be pointed out here that mirror machines have in fact been found to be stable (Post 1958). This may seem to be in contradiction with theoretical work which has predicted the existence of "interchange instabilities" for a magnetic field which bends concavely toward the plasma. However, care is necessary when these results are applied to experiments. They are valid for a very special situation where a surface current divides a vacuum region with magnetic field from a fieldfree plasma region. This is also pointed out by Berkowitz *et al.* (1958) who have shown that mirror configurations with volume currents can become stable.

A detailed report will be published later.

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